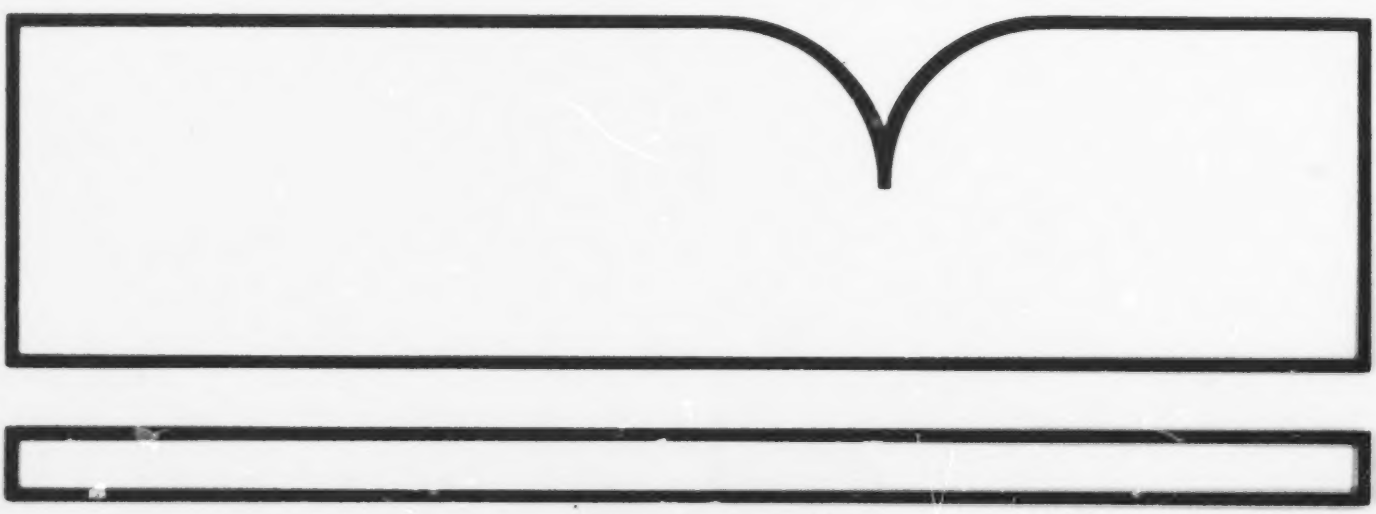
PB90-113077

Performance of Emissions Control Systems on Municipal Waste Combustors, 1989

(U.S.) Environmental Protection Agency, Research Triangle Park, NC

1989



U.S. Department of Commerce
National Technical Information Service
NTIS

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

AEERL-P-564

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/D-89/116	2.
3. R PB90-113077	
4. TITLE AND SUBTITLE: Performance of Emissions Control Systems on Municipal Waste Combustors	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Theodore G. Brna, Michael G. Johnston*, Clyde E. Riley*, and Charles C. Masser	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: See Block 12	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS: **EPA, Office of Research and Development** Air and Energy Engineering Research Laboratory **Research Triangle Park, NC 27711**	13. TYPE OF REPORT AND PERIOD COVERED: Published paper; June 1989
	14. SPONSORING AGENCY CODE: **EPA/600/13**

15. SUPPLEMENTARY NOTES: AEERL project officer is T. G. Brna, Mail Drop 65, 919/541-2683. (*)Johnston and Riley are with EPA's Office of Air Quality Planning and Standards. Presented at AWMA meeting, Anaheim, CA, 6/25-30/89.

16. ABSTRACT: The paper discusses the performance of emissions control systems on municipal waste combustors (MWCs). Regulations for MWCs are being developed by EPA under Section 111 of the Clean Air Act. To support this effort, data on gaseous pollutant emissions from MWCs and emissions control by flue gas cleaning systems are being collected and evaluated. Several EPA-supported field tests on modern MWCs have been performed and are reported here. The results are reported in terms of acid gas, trace organic, trace heavy metal, and particulate reductions for units with lime spray dryer/fabric filter (SD/FF) and lime spray dryer/electrostatic precipitator (SD/ESP) controls. Both control technologies achieved over 90% removal of HCl in the four tests reported. The three SD/FF systems removed 99% of the entering chlorinated dioxins/furans. The SD/ESP achieved 62% removal of the entering dioxins/furans. Metals (except mercury) and particulate control by the SD/FF systems was greater than 98%; however, similar measurements were not made for the SD/ESP system.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Hydrocarbons	Pollution Control	13B	
Emission	Furans	Stationary Sources	14G	
Wastes	Calcium Oxides	Municipal Waste Combustion	14E	07B
Combustion	Spray Drying		21B	07A, 13H
Heterocyclic Compounds	Electrostatic Precipitators	Dioxins		
		Lime Spray Drying	07C	13I
		Fabric Filters		

18. DISTRIBUTION STATEMENT: **Release to Public**	19. SECURITY CLASS *(This Report)*: **Unclassified** — 21. NO. OF PAGES: 19
	20. SECURITY CLASS *(This page)*: **Unclassified** — 22. PRICE: A03

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/D-89/116

PERFORMANCE OF EMISSIONS CONTROL SYSTEMS ON MUNICIPAL WASTE COMBUSTORS

Theodore G. Brna[a], Michael G. Johnston[b], Clyde E. Riley[b], and Charles C. Masser[a]
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Regulations for municipal waste combustors (MWCs) are being developed by EPA under Section 111 of the Clean Air Act. To support this effort, data on gaseous pollutant emissions from MWCs and emissions control by flue gas cleaning systems are being collected and evaluated. Several EPA-supported field tests on modern MWCs have been performed and are reported here. The results are reported in terms of acid gas, trace organic, trace heavy metal, and particulate matter reductions for units having lime spray dryer/fabric filter (SD/FF) and lime spray dryer/electrostatic precipitator (SD/ESP) controls. Both control technologies achieved over 90% removal of HCl in the four tests reported. The three SD/FF systems removed 99% of the entering chlorinated dioxins/furans. The SD/ESP achieved 62% removal of the entering dioxins/furans. Metals (except mercury) and particulate matter control by the SD/FF systems was greater than 98%, while similar measurements were not made for the SD/ESP system.

Presented at the
1989 Annual Meeting of the Air & Waste Management Association
Anaheim, CA.
June 25-30, 1989

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

---

[a] Air and Energy Engineering Research Laboratory
[b] Office of Air Quality Planning and Standards

INTRODUCTION

In July 1987, the U. S. Environmental Protection Agency (EPA) announced its intent to regulate municipal waste combustors (MWC's) under Section 111 of the Clean Air Act.[1] This announcement was made concurrently with the issuance of a Report to Congress[2] on MWC's which summarized information gathered by EPA on the population and distribution of MWC's, MWC emissions, good combustion practices, flue gas cleaning technologies, sampling and analysis methods, and risk assessment. The emissions data base in this study focuses on four air pollutant categories: acid gases (HCl, SO_2), trace organic compounds (primarily dioxins and furans), trace metals, and particulate matter. The report influenced the structure of an EPA field test program by revealing areas where additional data were needed to support EPA's regulatory development effort. The report also provided information on sites where modern MWC technology was being used.

Major components of the on-going EPA field test program are to characterize and to determine the performance of flue gas cleaning systems used with modern MWC units in the U. S. Work reported here focuses on results of emission tests conducted across several flue gas cleaning systems. In the EPA program, effective flue gas cleaning is being studied as a complement to efficient municipal solid waste (MSW) combustion for minimizing air pollutant emissions as well as emissions to other media. The fact that modern flue gas cleaning systems can effectively reduce pollutant emissions from MWC's should not preclude minimizing combustor emissions through the employment of good combustion practices.[3]

In the United States, state-of-the-art MWC units now often use a lime spray dryer absorber (SD) for acid gas control in conjunction with either a fabric filter (FF) or an electrostatic precipitator (ESP) for particulate matter control. These dry scrubber combinations are also effective in removing the other pollutants such as toxic organics (dioxins/furans) and metals. Field test results are reported here for three SD/FF systems and one SD/ESP system. Test objectives at each test site were identical and included (1) characterization of selected pollutant emissions leaving the combustors, and (2) evaluation of the performance of the SD/FF's and SD/ESP on the selected pollutants.

TEST PROGRAM

The EPA field test program for MWC's currently encompasses five sites and involves three mass burn (MB) and two refuse-derived fuel (RDF) units. A description of each test site and the scope of emissions testing is discussed below.

Two of the mass burn units for which EPA tests have been completed (Marion County, OR, and Millbury, MA) are conventional waterwall energy recovery units. The Marion County facility is owned and operated by Ogden Martin Systems, Inc., and consists of two 275-tpd* combustors with an SD/FF (Teller) control system. Testing at Marion County at the inlet and outlet of the SD/FF for dibenzo-p-dioxins (CDD), chlorinated dibenzo-furans (CDF), heavy metals, and particulate matter, as well as outlet only measurements for acid gases (SO_2 and HCl), carbon monoxide (CO), and nitrogen oxides (NO_x), was conducted in September 1986 under normal combustor and SD/FF operating conditions.[4] Similar tests under start-up and shutdown conditions were conducted in June 1987.[5,6] Because of low internal standard recoveries in the CDD/CDF analysis for samples at the spray dryer inlet in EPA's September 1986 test, additional inlet gas samples were collected in February 1987.

Further testing at Marion County was to consist of two planned phases, characterization and performance. The characterization phase was completed in June 1987 and consisted of an evaluation of the combustor and the SD/FF under a variety of operating conditions. The performance test phase was not undertaken because modifications to the spray dryer system to allow independent control of the approach to saturation temperature and reagent (stoichiometric) ratio were not completed by the facility.

The tests at Millbury, MA, on one of the two 750-tpd mass burn units were made during permit compliance testing in February 1988.[7] The unit is equipped with an SD/ESP. The EPA sponsored the collection of CDD/CDF samples at the inlet to the SD and the facility, owned and operated by Wheelabrator Environmental Systems, Inc., sponsored the collection for similar samples at the outlet of the ESP. All tests were performed by the same contractor.

The third mass burn unit, Montgomery County South in Dayton, OH, is a municipally owned refractory wall unit with three 300-tpd rotary kiln combustors. The incinerator includes a primary ignition and combustion chamber, a rotary kiln, a secondary mixing chamber where combustion is completed, and a spray quench chamber followed by an ESP. Limestone is injected into the furnace for acid gas control. The EPA testing at Dayton began in October 1988 and was completed in December 1988. Tests were conducted at different ESP temperatures and sorbent addition rates, both into the furnace and into the duct, to evaluate the

*The Appendix provides English to metric unit conversions.

effects of temperature and sorbent rate on the control of the full range of MWC air emissions. Results will be available in August.

Emissions testing at the two RDF units were conducted simultaneously with permit compliance tests. Tests at the Maine Energy Recovery Company 600-tpd (2 units) Biddeford, ME, facility were performed in December 1987[4], and those on the Combustion Engineering 2000-tpd (three units) Mid-Connecticut facility in Hartford were performed in July 1988.[5] Both facilities were tested at the inlet and outlet of the SD/FF control system. Extensive characterization and performance tests on the Hartford unit were also performed in January and February 1989 as part of a joint Environment Canada/EPA project. The acid gas test results of the characterization test were recently reported but are not discussed here.

The samples collected during the test program may be placed into two main categories: flue gas samples and process stream samples. The emission measurements were obtained from the flue gas samples by both manual methods and instruments, and from the process stream samples (ash, residue, lime slurry, and Tesisorb).

An integral part of all testing was the monitoring and recording of combustor and control device operating data. Combustor operating conditions typically monitored included underfire and overfire air flows, gas temperatures at selected points, steam flow, CO, O_2, and CO_2. Air pollution control device operating conditions monitored included inlet and outlet gas temperatures, sorbent feed rates, inlet SO_2 concentrations, fabric filter pressure drop, and ESP electrical conditions. The operating data were generally obtained in part from facility measurements and in part from measurements using test contractor or EPA equipment. In most cases air emission test measurements were subject to EPA quality control and quality assurance requirements.

DISCUSSION OF DATA AND RESULTS

CDD/CDF

Results of the CDD/CDF measurements obtained during normal operation at each site are given in Table I. Comparison of the average uncontrolled CDD and CDF results shows that the uncontrolled CDF values were at least twice the CDD values at each site. The RDF units equipped with SD/FF's had the highest uncontrolled CDD and CDF emissions (about 900 ng/dscm) and the highest removal efficiencies (>99%). With the exception of Millbury, CDD removal exceeded 96%, CDF removal exceeded 99%, and total CDD+CDF removal exceeded 98% at all sites tested.

Millbury, which had the lowest uncontrolled organic emissions recorded, achieved the lowest average removal efficiencies, 66.6, 60.5, and 62% for CDD, CDF, and CDD+CDF, respectively. With the exception of Millbury, total controlled CDD+CDF emissions were less than 5 ng/dscm for all sites. The CDD + CDF outlet concentration at Millbury was 62 ng/dscm.

The results obtained clearly demonstrate that SD/FF systems applied either to mass burn or RDF combustors are very effective in controlling CDD + CDF emissions. All three systems tested achieved better than 98% control. In contrast, the SD/ESP tested achieved only 62% control. Although the ESP operated at 255°F and was demonstrated to be an effective particulate collector achieving an outlet concentration of 0.002 gr/dscf (conditions favoring good CDD/CDF control), the SD/ESP was not as effective as the SD/FF in reducing CDD + CDF emissions. It can be speculated that some additional control of organics is achieved by the FF's as a result of the adsorption of condensible organics on the particulate cake collected on the FF bags.

It should be noted that combustion conditions at Biddeford and Mid-Conn were not optimized. Biddeford was experiencing problems with the RDF feed conveyor, resulting in some temporal, non-uniform combustion conditions as evidenced by periodic increases in CO emission levels. Also, Mid-Conn had not completed all of their combustor performance tests to optimize the RDF combustor. The less than optimum combustion conditions at Mid-Conn were evidenced by relatively high CO levels. Valid comparisons of relative furnace emissions between RDF and mass burn combustors should be attempted only after optimum operating conditions are obtained in RDF combustors.

Acid Gases

Data on HCl concentrations in the flue gas were collected at all sites. Performance data for each run (corrected to 12% CO_2), including measured inlet/outlet concentrations and removal efficiencies achieved, are shown in Table II. The overall removal efficiency across the SD and FF averaged 90.7% for the baseline tests at Marion County when the HCl inlet concentration averaged 639 ppmv and the SD outlet temperature was 300°F. About 75% of the total HCl removal occurred in the SD. During tests when the SD outlet temperature was varied from the baseline value of 300°F, the overall HCl removal changed as expected. It decreased to 78 and 71.5% at 330 and 360°F, respectively, and increased to 97.5% at an outlet temperature of 262°F. The HCl removal across the SD during these test runs ranged from 58 to 78%.

Although the average inlet HCl concentrations at the three other test sites were different than at Marion County, higher at Millbury, and lower at Biddeford and Hartford, the overall HCl removals were higher than at Marion County. Each sample run at all three sites recorded better than 98% removal, and the average of all sample runs for all three sites exceeded 99%. A likely contributing factor to the better performance demonstrated at these three sites is the SD outlet temperature. The SD outlet temperatures and particulate collector outlet temperatures were lower at the three sites than at Marion County. The average SD temperature at Millbury, which has an SD/ESP system, was the lowest at 255°F. The SD temperatures at Biddeford and Hartford, both SD/FF systems, were 278 and 271°F, respectively. Another factor could be differences in the quantity of sorbent added. However, because sorbent stoichiometric ratios at Marion County and Biddeford could not be determined accurately, performance related to sorbent variations cannot be compared.

Table III presents SO_2 data for the Marion County, Biddeford, and Millbury tests. No SO_2 removal data were obtained during the Hartford tests. At baseline conditions, the SD/FF unit at Marion County achieved an overall SO_2 removal of 44%, with about 33% SO_2 removal in the SD, at an average inlet SO_2 concentration of 429 ppmv (dry, corrected to 12% CO_2). The lime slurry feed to the SD is prepared at a fixed solids concentration, and the slurry feed rate is used to control the SD outlet temperature. Thus, increasing the lime slurry feed rate at a given unit steam load increases the reagent (stoichiometric) ratio and simultaneously decreases the SD outlet gas temperature.

The flue gas cleaning systems at Biddeford, Millbury, and Hartford are designed to control the reagent ratio and SD outlet temperature independently. The average SO_2 removals measured for all runs at Biddeford and Millbury were 77.6 and 79.4%, respectively, with Biddeford having an average inlet SO_2 concentration of 91.9 ppmv and Millbury a concentration of 285 ppmv (both corrected to 12% CO_2). It should be noted that about 45 minutes after Run 2 at Biddeford began, the plant operator doubled the slurry feed rate after learning that the SO_2 removal was below the desired value. This change raised the overall removal from 65.9% in Run 1 to 72.4% in Run 2 and 89.5% in Run 3. The SO_2 inlet concentration at Millbury ranged from 243 to 307 ppmv, and the average overall SO_2 removal achieved ranged from 76.7 to 81.7%. As noted in the discussion on HCl removal earlier, the average SD outlet temperature at Marion County, Biddeford, and Millbury was 300, 278, and 255°F, respectively.

Particulate

Particulate data are listed for each site in Table IV. As indicated, all three SD/FF systems achieved greater than 99.5% control efficiency. The average outlet particulate emission ranged from 0.0023 gr/dscf at Marion County to 0.0144 gr/dscf at Biddeford. Marion County also had the lowest particulate loading at the SD inlet, averaging 0.881 gr/dscf while the two RDF units had higher loadings, as expected because of semi-suspension firing of the RDF. The inlet loading averaged 3.21 gr/dscf at Biddeford and 2.52 gr/dscf at Mid-Conn.

Metals

Table V summarizes the metals emission data collected at Marion County, Biddeford, and Hartford, each equipped with an SD/FF. Lead was the predominant metal measured at the SD inlets. As shown in Table V, the SD/FF's all achieved over 98% control of the heavy metals measured, except during Run 4 at Marion County when the FF was bypassed and during Run 1 at Hartford when the mercury removal was only 61%. Since RDF units have higher particulate emissions from their combustion chambers than mass burn units, comparison of metal emissions from these different combustor types should consider metal emission rates as percentages of total particulate emissions. Another factor that has to be considered in comparing metal emissions is furnace feed rate. In the tests reported here, the MSW and RDF feed rates were not measured; therefore, metal emissions per unit of feed are not available.

In addition to determining trace metals air emissions, also determined at Biddeford were trace metal concentrations in the ashes/residues. The lead concentration in the FF residue averaged 1,680 µg/g and ranged from 537 to 2,800 µg/g for the three test runs. The cyclone ash averaged 2,300 µg lead/g ash and ranged from 2,200 to 2,400 µg/g. The mercury content varied from <28 µg/g in the cyclone ash to 19.5 and <16 µg/g in the FF solids and bottom ash, respectively. Heavy metal concentrations in the lime slurry feed were low, the maximum concentration being 3.8 µg/g for arsenic.

CONCLUSIONS

Based on results from compliance and characterization tests at four modern MWC's, it is concluded that:

1. SD/FF and SD/ESP systems are effective in controlling acid gas emissions (HCl, SO_2) when operated within their design limits. These systems can remove 90% or more HCl and 70% or more SO_2.

2. The SD/FF systems attained an average CDD removal of 98.7% and an average CDF removal of 99.5% for an average overall removal of 99.4%. The SD/ESP removed less than 70% of these pollutants although operating with a lower SD outlet gas temperature.

3. The total CDF concentrations, both uncontrolled and controlled, were generally greater than the total CDD values. The inlet total CDD concentrations for the RDF units were several times greater than those of the mass burn units. However, effective operation of their flue gas cleaning systems resulted in low controlled emissions, even lower than those during some test runs for the mass burn units.

4. Limited trace metal results were obtained, the most extensive set being for the Biddeford unit. Lead was the dominant metal, having the highest concentrations at the inlet to the spray dryer. Cadmium and total chromium alternated as the next highest concentrations at the Marion and Biddeford units, respectively. The flue gas cleaning systems were effective in removing all metals studied by over 98%, except mercury whose removal ranged from 60.6 to 99.7%.

5. All flue gas cleaning systems were effective in removing particulate matter. The average removal efficiencies exceeded 99% for all test runs. The mass burn units, as expected, had lower inlet particulate loadings than did the RDF units.

Table VI summarizes the removal efficiencies for the different pollutants at the facilities tested.

REFERENCES

1. Environmental Assessment of Municipal Waste Combustor Emissions Under the Clean Air Act (40 CFR, Part 60), Federal Register, Vol. 52, No. 129, Tuesday, July 7, 1987, pp. 25399-25408.

2. Municipal Waste Combustion Study: Report to Congress, EPA/530-SW-021a (NTIS PB87-206074), June 1987, U. S. Environmental Protection Agency, Office of Solid Waste, Washington, DC.

3. Municipal Waste Combustion Study: Combustion Control of Organic Emissions, EPA/530-SW-021c (NTIS PB87-206090), June 1987, U. S. Environmental Protection Agency, Office of Solid Waste, Washington, DC.

4. Municipal Waste Combustion Multipollutant Study: Summary Report, Marion County Solid-Waste-to-Energy Facility, Ogden Martin Systems of Marion, Inc., Brooks, OR, EMB Report No. 86-MIN-03A, September 1988, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

5. Municipal Waste Combustion Multipollutant Study: Shutdown/Startup Emission Test Report, Marion County Solid-Waste-to-Energy Facility, Ogden Martin Systems of Marion, Inc., Brooks, OR, EMB Report No. 87-MIN-04A, September 1988, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

6. Municipal Waste Combustion Multipollutant Study: Characterization Emission Test Report, Marion County Solid-Waste-to-Energy Facility, Ogden Martin Systems of Marion, Inc., Brooks, OR, EMB Report No. 87-MIN-04, September 1988, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

7. Municipal Waste Combustion Multipollutant Study: Emission Test Report, Wheelabrator Resource Recovery Facility, Millbury, MA, EMB Report No. 88-MIN-07, 1988, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

8. Municipal Waste Combustion, Multi-Pollutant Study, Emission Test Report, Maine Energy Recovery Company, Refuse Derived Fuel Facility, Biddeford, Maine, Volume I, Summary of Results, EPA-600/8-89-064a, July 1989, U.S Environmental Protection Agency, Office of Research and Development, Washington, DC.

9. Municipal Waste Combustion Multipollutant Study: Refuse-Derived Fuel Summary Report, Mid-Connecticut Resource Recovery Facility, Hartford, CT. EMB Report No. 88-MIN-09A, January 1989, U. S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory and Office of Air Quality Planning and Standards, Research Triangle Park, NC.

10. Air Emissions Compliance Test Results and Related Data at the Mid-Connecticut Resource Recovery Facility, Hartford, CT, Report (August 18, 1988) prepared by TRC Environmental Consultants, Inc., for Combustion Engineering, Inc., Windsor, CT.

TABLE I. AVERAGE CDD AND CDF AT SITES TESTED[a]

Location/Date	Total Uncontrolled Emissions ng/dscm at 12% CO_2			Total Controlled Emissions ng/dscm at 12% CO_2			Removal, %			Ref.
	CDD	CDF	CDD+CDF	CDD	CDF	CDD+CDF	CDD	CDF	CDD+CDF	
Unit No. 1[b] Marion County Brooks, OR September 1986 February 1987	31.2 (24.4-36.8)[c]	150 (85.6-187)	182 (110-219)	1.01 (0.69-1.34)	1.19 (0.97-1.42)	2.2 (1.66-2.76)	96.8	99.2	98.8	4
Unit A[d] MERC Biddeford, ME December 1987	288 (239-342)	590 (560-594)	877 (833-957)	1.3 (1.0-1.6)	2.9 (2.4-3.5)	4.3 (3.5-5.0)	99.5	99.5	99.5	8
Unit No. 2[e] Wheelabrator Millbury, MA February 1988	44.3 (32.6-52.2)	120.1 (96.6-153)	164.3 (142.4-205)	14.8 (9.2-30.4)	47.4 (33.8-79.7)	62.2 (41.8-110)	66.6	60.5	62.1	7
Unit No. 11[d] Mid-Conn Hartford, CT July 1988	328 (239-378)	668 (544-893)	996 (783-1259)	0.271 (0.000-0.605)	0.375 (0.000-0.769)	0.646 (0.000-1.37)	99.9	99.9	99.9	9

[a] Values of CDD and CDF do not include not-detectable congeners (i.e., those below minimum detection limits).
[b] Uncontrolled values are averages from Runs 1-4 collected by EPA in February 1987, and the controlled values are averages of Runs 2 and 3 collected by Ogden Projects, Inc., in September 1986. Low recovery of internal standards in samples collected by EPA in September 1986 led to the February 1987 tests under similar unit operating conditions.
[c] The range of values is shown in parentheses under each average value.
[d] Values indicated are based on three test runs.
[e] Values indicated are based on five test runs.

NOTE: Summed values and removals were determined before rounding off; thus, the values shown may differ slightly from those calculated using the listed values.

TABLE II. HCl CONCENTRATION AND REMOVAL

Location/Date	Run No.	HCl Concentration, ppmv (dry) @ 12% CO_2			Removal Efficiency,%		Average Temperature, °F			Ref.
		Spray Dryer Absorber		Fabric Filter or ESP Outlet	Spray Dryer Absorber	Overall System	Spray Dryer Absorber		FF or ESP Outlet	
		Inlet	Outlet[a]				Inlet	Outlet[a]		
Unit No. 1	1	646	225	83.7	65.2	87.0	432	300	280	6
Marion County	2	631	183	35.0	71.0	94.5	430	300	280	
Brooks, OR	Avg.	639	204	59.4	68.1	90.7	431	300	280	
June 1987	10	814	180	20.4	77.9	97.5	436	262	252	
	11A	718	295	158	58.9	78.0	434	330	302	
	11B	750	313	214	58.3	71.5	461	360	334	
Unit A	1	478	63	9	86.8	98.1	374	277	268	8
MERC	2[b]	566	8	4	98.6	99.3	364	278	268	
Biddeford, ME	3	540	1[c]	3	ND[c]	99.4	384	279	268	
December 1987	Avg.	528	36[d]	5	93.2[d]	99.1	374	278	268	
Unit No. 2	1	764	NA[e]	9.2	NA[e]	98.8	438	255	254	7
Wheelabrator	2	672	NA	4.2	NA	99.4	441	255	254	
Millbury, MA	3	574	NA	4.0	NA	99.3	432	255	253	
February 1988	Avg.	670	NA	5.8	NA	99.1	437	255	254	
Unit No. 11	1	424	NA	5.3	NA	98.8	379	270	241	10
Mid-Conn	2	472	NA	3.1	NA	99.3	375	266	234	
Hartford, CT	3	457	NA	4.3	NA	99.1	384	277	250	
July 1988	Avg.	451	NA	4.2	NA	99.1	379	271	242	

[a] Also referred to as midpoint.
[b] Slurry feed doubled 45 minutes into run and then held constant for remainder of this and Run 3.
[c] Questionable value and efficiency not determined (ND) for this run.
[d] Average based on Runs 1 and 2.
[e] NA means not available or not applicable.

NOTE: Average (Avg.) values and removal efficiencies were determined before rounding off; thus, the values shown may differ slightly from values calculated from listed values.

TABLE III. SO_2 CONCENTRATIONS AND REMOVAL

Location/Date	Run No.	SO_2 Concentrations ppmv (dry) @ 12% CO_2			Removal Efficiency, %		Average Temperature, °F			Ref.
		Spray Dryer Absorber		Fabric Filter or ESP Outlet	Spray Dryer Absorber	Overall System	Spray Dryer Absorber		FF or ESP Outlet	
		Inlet	Outlet[a]				Inlet	Outlet[a]		
Unit No. 1	1	559	450	383	19.5	31.5	432	300	280	6
Marion County	2	299	128	100	57.0	66.7	430	300	280	
Brooks, OR	Avg.	429	289	241	32.6	43.7	431	300	280	
June 1987	10	383	326	108	14.8	71.8	436	262	252	
	11A	470	523	484[b]	-11.1[b]	-3.0[b]	434	330	302	
	11B	118[b]	178	165	-50.4[b]	-39.4[b]	461	360	334	
Unit A	1	83.3	NA[c]	28.4	NA	65.9	374	277	268	8
MERC	2	76.9	NA	21.2	NA	72.4	364	278	268	
Biddeford, ME	3	115	NA	12.1	NA	89.5	384	279	268	
December 1987	Avg.	91.9	NA	20.6	NA	77.6	374	278	268	
Unit No. 2	1	307	NA	56.0	NA	81.7	438	255	254	7
Wheelabrator	2	243	NA	49.5	NA	79.6	441	255	254	
Millbury, MA	3	305	NA	71.0	NA	76.7	432	255	253	
February 1988	Avg.	285	NA	58.8	NA	79.4	437	255	254	

[a] Also referred to as midpoint.
[b] Instrument inaccuracies due to measuring concentrations outside of calibration range (i.e., measuring low concentrations while calibrated to measure high concentrations).
[c] Not available.

NOTE: Average (Avg.) values and removal efficiencies were determined before rounding off; thus, the values shown may differ slightly from values calculated from listed values.

TABLE IV. PARTICULATE MATTER EMISSION (Corrected to 12% CO_2) AND REMOVAL

Location/Date	Run No.	Particulate Matter Emission gr/dscf: Spray Dryer Absorber Inlet	Particulate Matter Emission gr/dscf: Fabric Filter Outlet	Removal Efficiency, %	Ref.
Unit No. 1	1	1.05	0.0037	99.5	
Marion County	2	1.12	0.0018	99.8	
Brooks, OR	3	0.74	0.0013	99.8	
September 1986	Avg.	0.88[a]	0.0023	99.7[a]	4
Unit A	1	3.23	0.0095[b]	99.7	
MERC	2	2.85	0.0142	99.5	
Biddeford, ME	3	3.53	0.0194	99.5	
December 1987	Avg.	3.20	0.0144	99.6	8
Unit No. 11	1	2.57	0.0021	99.9	
Mid-Conn	2	2.25	0.0041	99.8	
Hartford, CT	3	4.79[c]	0.0059	99.9	
July 1988	Avg.	2.41[d]	0.0040	99.8	9

[a] Based on Runs 1-6. Inlet emission values for Runs 4, 5, and 6 were: 0.848, 0.791, and 0.739 gr/dscf, respectively

[b] Not determined from diluent data as Method 3 sampling train leaked. Inlet results to spray dryer absorber for Run 1 used to obtain corrected value.

[c] Includes sootblowing sequence.

[d] Based on Runs 1 and 2, as Run 3 included sootblowing.

NOTE: Because of rounding off of emission data, the removal efficiency may differ slightly from that listed.

TABLE V. EMISSION RATES OF SELECTED METALS (Corrected to 12% CO_2)

Location:	Unit 1, Marion County, Brooks, OR				Unit A, MERC, Biddeford, ME				Unit 11, Mid-Conn, Hartford, CT			
Test Date:	September 1986 (Ref. 4)				December 1986 (Ref. 8)				July 1988 (Ref. 9, 10)			
Run No.	4	5	6	Avg.	1	2	3	Avg.	1	2	3	Avg.
Uncontrolled Metal, µg/dscm												
Arsenic					507	543	652	567				
Cadmium	1,150	1,180	950	1,090	1,090	1,090	1,560	1,250				
Chromium	453	262	520	412	2,520	2,750	3,970	3,080				
Lead	16,400	19,400	24,200	20,000	28,100	28,200	34,900	30,400				
Mercury					523	330	432	428	320	1,163	1,051	845
Controlled Metal, µg/dscm												
Arsenic					0.0677	2.75	3.88	2.23	<2.6	<3.0	<3.0	<2.9
Cadmium	17	2.8	2.2	2.5[a]	5.42	4.78	15.7	8.62				
Chromium	ND[b]	0.12[c]	0.19	0.16[a]	1.40	2.31	5.80	3.17	59	<50	<25	<45
Lead	180	14	21	18[a]	68.4	72.9	185	109	<5	<5	<7	<6
Mercury					ND[a]	0.8	2.8	1.8	126	3.54	16.2	48.6
Removal Efficiency, %												
Arsenic					99.9	99.5	99.4	99.6				
Cadmium	98.5	99.8	99.8	99.8	99.5	99.6	99.0	99.4				
Chromium	100	99.9	99.9	99.9	99.9	99.9	99.9	99.9				
Lead	98.9	99.9	99.9	99.9	99.8	99.7	99.5	99.7				
Mercury						99.8	99.4	99.6	60.6	99.7	98.5	94.2

[a] Average of Runs 5 and 6 as baghouse was bypassed during Run 4, causing higher emissions.
[b] ND means none detected.
[c] Analyte detected at detection limit.

NOTE: Blank spaces indicate no data collected or insufficient data to calculate efficiency.

TABLE VI. SUMMARY OF AVERAGE REMOVAL EFFICIENCIES (%) IN MWC FLUE GAS CLEANING SYSTEMS

Type of MWC	Mass Burn		Refuse-derived Fuel (RDF)	
Unit/Location	1/Marion County	2/Millbury	A/Biddeford	11/Mid-Conn
Flue Gas Cleaning System	SDA/FF	SDA/ESP	SDA/FF	SDA/FF
Pollutants				
Acid Gas				
HCl	90.7	99.1	99.1	99.1
SO_2	43.7	79.4	77.6	NA[a]
Organics				
CDD	96.8	66.6	99.5	99.8
CDF	99.2	60.5	99.5	99.9
CDD+CDF	98.8	62.1	99.5	99.9
Particulate Matter	99.7	NA	99.6	99.8
Metal				
Arsenic	NA	NA	99.6	NA
Cadmium	99.8	NA	99.4	NA
Chromium (total)	99.9	NA	99.9	NA
Lead	99.9	NA	99.7	NA
Mercury	NA	NA	99.6	94.2

[a] NA means not available.

NOTE: All efficiencies are based on mass, except for the acid gases.

APPENDIX

CONVERSION FACTORS

English Unit	Times	Yields Metric Unit
ton/day = tpd	9.07×10^{-1}	tonne/day
gr/dscf	2.288×10^{3}	ng/dscm*
°F	5/9 (°F - 32)	°C

---

*dscm = dry standard cubic meter